Learning 4.0

Advanced Simulation, Immersive Experiences and Artificial Intelligence, Flipped Classrooms, Mentoring and Coaching

edited by
Fernando Salvetti and Barbara Bertagni

Works by P. Angelotti, D. Araya, N. Argenziano, B. Bertagni, J. Bradburne, T. Brenner, B. Chirizzi, E. Filippouli, D. Guralnick, P.L. Ingrassia, M. Latini, F. Salvetti, A. Scuderi, M. Waldrop, C. Wieman

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Foreword: Learning 4.0 & STEAM Education

by *Fernando Salvetti* and *Barbara Bertagni*

Learning 4.0 and STEAM education: two important trends our book is discussing.

4.0 is the ongoing technology revolution: a revolution that is changing the way we live, work and relate to one another. Billions of people connected by mobile devices, unprecedented processing power, storage capabilities and access to knowledge. The confluence of artificial intelligence, robotics, quantum computing and the Internet of things - to name a few.

What is STEAM? It's the extension of an acronym that originally stands for science, technology, engineering and math, with the arts added because STEM alone misses several key components that many employers, educators and parents have voiced as critical to thrive in the present and rapidly approaching future. It's a movement that has been taking root over the past several years and is surging forward as a positive mode of action to truly meet the needs of a 21st Century society.

STEAM is an educational approach to learning that uses science, technology, engineering, the arts and mathematics as access points for guiding learner inquiry, dialogue and critical thinking. The end results are learners who take thoughtful risks, engage in experiential learning, persist in problem-solving, embrace collaboration and work through the creative process. STEAM is a way to take the benefits of STEM and complete the package by integrating these principles in and through the arts. STEAM takes STEM to the next level: it allows learners to connect their learning in these critical areas together with arts practices, elements, design principles and standards to provide the whole pallet of learning at their disposal. STEAM removes limitations and replaces them with wonder, critique, inquiry and innovation.

The STEAM Model is not so far from the Italian Renaissance approach developed within a typical workshop. The “head-shop” performs as a learning facilitator that defines the problem, helps learners gather background research and specifies the requirements. The learners do the rest: creating alternative solutions and choosing the best one, doing development work, building a prototype, testing and redesigning. Just to name a very famous example: Leonardo da Vinci.

How can we think like Leonardo to empower ourselves? By giving ourselves the time and space to wonder and contemplate. Being committed to test knowledge through experience, viewing the situations from multiple perspectives. Honing personal sensory awareness and mindfulness. Embracing ambiguity, paradox and uncertainty. Trying to balance between science and art, logic and imagination, because balancing apparent opposites gives us a more complete view of the world and allows us to think with our whole mind, rather than just a portion of it. Cultivating ambidexterity, fitness and poise. Being aware of the big picture and open to systems thinking: a recognition and appreciation for the connectedness of all things and phenomena.

In a nutshell: it is no longer productive to continue offering education in the traditional way! What we know about learning from cognitive psychology is that people learn by practicing and getting feedback that tells them what they’re doing right and wrong and how to get better.

Educators and education leaders would do well to focus less on translating knowledge - notably transferring existing knowledge to learners - and more on the processes of entrepreneurial learning and creativity. The key is focusing on synthesis and problem solving by leveraging knowledge across disciplines: systems thinking. In this sense, the liberal arts, as well as the Renaissance approach, provide an interesting model to work from.

As citizens of our “glocal” world, we are in need to share an epistemic common currency enabling us to commit ourselves to a particular attitude of open inquiry; being aware that commitment is distinct from absolute belief.

Almost all around the world, excluding some very authoritarian countries, the current buzzwords are all about ambiguity and complexity, multi-level problem setting and solving, systems thinking, communication, creativity and disruptive innovation, cognitive flexibility, knowledge sharing, contextual and cross-cultural intelligence - at any level and as an output of any educational process.

Governments, institutions and corporations are being reshaped, as are systems of education, healthcare and transportation, among many others. So, we are in need of rethinking learning approaches and paths, to grasp the challenges and opportunities of the fourth industrial revolution that is growing the integration of many different disciplines and discoveries. For instance, the interdependence between digital fabrication technologies and biology, or the link between ambient computing and our personal devices becoming more and more embedded within our personal ecosystems - listening and talking to us, and trying to anticipate our needs.

The pervasive power of digitalization and information technology is a key feature of the 4.0 world, accompanied by the artificial intelligence that is infiltrating our lives at an unprecedented speed. As an educator, are you an AI-theist, a doubter or a believer? In any case, it is time to turn on the light, stop worrying about sci-fi scenarios and start focusing on AI's actual challenges. From a practical perspective: one-third of all jobs will be converted into software, robots and smart machines by as early as 2025. Meanwhile, some 65 percent of children in grade school today are predicted to work in jobs that have yet to be invented.

What are you doing as an educator to grasp the 4.0 revolution? Are you fine with a STEAM approach? Are you able to deal with advanced simulation in enhanced reality environments (mixing virtual, augmented and mixed reality)? Or with immersive experiences or flipped classrooms? What about interactive infographics, or online, just-in-time and on-the-job learning? What about mentoring, coaching, learning facilitation, gamification, Socratic dialogues, adaptive learning, self-directed and learner-generated activities or ATAWAD learning (anytime, anywhere, any device)?

STEM Education: Active Learning or Traditional Lecturing?

by *Carl Wieman*

1. Active Learning Versus Traditional Lecturing

College lecture classes, in which students are primarily listening and taking notes, have been around for more than 900 years. Lately, a handful of science and engineering professors have been experimenting with a more innovative way of teaching science, especially at the introductory level. The idea is to have students spend their class time solving problems and engaging in activities that are designed to help them think like scientists instead of listening passively to an expert.

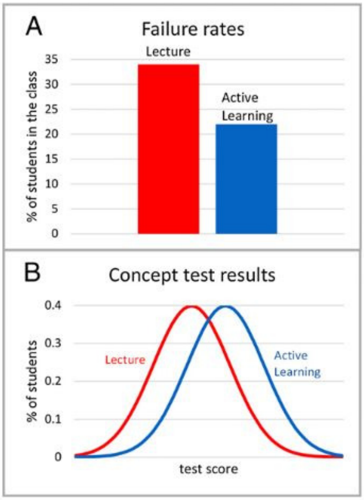
Designing a course that includes active learning requires more content knowledge, not less, than teaching in the classic lecture mode. It's not a cop out or losing the importance of expertise by the faculty. If a teacher uses active learning techniques, he or she is still telling students things; but it's in response to their questions, their needs to solve a problem, and so they learn much more from it. So, a teacher has to work hard to use active learning in the class and has to carefully structure problems and activities to get students to think like a scientist, mathematician, etc.

As the number of research studies has grown, it has become increasingly clear to researchers that active learning methods achieve better educational outcomes. The possibilities for improving post-secondary STEM education through more extensive use of these research-based teaching methods were reflected in two important recent reports (Singer, Nielsen, Schweingruber 2012; PCAST 2012). However, the size and consistency of the benefits of active learning remained unclear. In PNAS, Freeman et al. (2014), it provides a much more extensive quantitative analysis of the research on active learning in college and university STEM courses than previously existed. It was a massive effort involving the tracking and analyzing of 642 papers spanning many fields and publication venues and a very careful analysis of 225 papers that met their standards for the meta-analysis. The results that emerge from this meta-analysis have important implications for the future of STEM teaching and STEM education research.

In active learning methods, students are spending a significant fraction of the class time on activities that require them to be actively processing and applying information in a variety of ways, such as answering questions using electronic clickers, completing worksheet exercises and discussing and solving problems with fellow students. The instructor designs the questions and activities and provides follow-up guidance and instruction based on student results and questions. The education research comparing learning from this method with that from the lecture method has usually been carried out by scientists and engineers in the multiple respective disciplines, because the desired learning and the implementation of the teaching methods are quite discipline specific and require substantial disciplinary expertise. Also, good active learning tasks simulate authentic problem solving and therefore teaching with these methods typically demands more instructor subject expertise than does a lecture.

Probably the most striking result in the analysis by Freeman at al. (2014) is that the impact of active learning on educational outcomes is both large and consistent. The authors examined two outcome measures: the failure rate in courses and the performance on tests. They found the average failure rate decreased from 34% with traditional lecturing, to 22% with active learning, whereas performance on identical or comparable tests increased by nearly half the standard deviation of the test scores (an effect size of 0.47). These benefits of active learning were consistent across all of the different STEM disciplines and different levels of courses (introductory, advanced, majors, and non-majors) and across different experimental methodologies. Although the average improvement on tests of all types is substantial, perhaps more notable is the larger improvement on concept inventory (CI) tests, where the effect size is 0.88. CIs are carefully developed tests that probe the differences between how scientists and students think about and use particular scientific concepts. As typically used, CIs also correct for the level of student knowledge at the start of a course and therefore provide a direct measure of the amount learned. Although limited in their scope, CIs are better than instructor-prepared examinations for measuring how well the students have learned to think like scientists.

Fig. 1



It is not surprising that the effect size from active learning is larger on CIs. Nearly all techniques labeled as active learning include those features known to be required for the development of expertise (Eriksson 2006); in this case, thinking like an expert in the discipline.

The active learning methods are designed to have the student working on tasks that simulate an aspect of expert reasoning and/or problem-solving, while receiving timely and specific feedback from fellow students and the instructor that guides them on how to improve. These elements of authentic practice and feedback are general requirements for developing expertise at all levels and disciplines and are absent in lectures. Because CI tests are specifically designed to probe expertise developed during a course, they are particularly sensitive to these differences in instructional methods. The relationship between active learning and general requirements for expertise development may also explain the consistency of the benefits across the different disciplines and levels of courses.

The implications of these meta-analysis results for instruction are profound, assuming they are indicative of what could be obtained if active learning methods replaced the lecture instruction that dominates US postsecondary STEM instruction. With a total annual enrollment in STEM courses of several million, a reduction in average failure rate from 34% to 22% would mean that an enormous number of students who are now failing STEM courses would instead be successfully completing them. The expected gains in learning for all students in STEM courses are equally important. However, such gains should be considered only the minimum of what is possible.

It is no longer appropriate to use lecture teaching as the comparison standard and instead, research should compare different active learning methods, because there is such overwhelming evidence that the lecture is substantially less effective. This makes both ethical and scientific sense. If a new antibiotic is being tested for effectiveness, its effectiveness at curing patients is compared with the best current antibiotics and not with treatment by bloodletting. However, in undergraduate STEM education, we have the curious situation that, although more effective teaching methods have been overwhelmingly demonstrated, most STEM courses are still taught by lectures that are the pedagogical equivalent of bloodletting.

Should the goals of STEM education research be to find more effective ways for students to learn or to provide additional evidence to convince faculty and institutions to change how they are teaching? The question cannot be avoided. So how, ideally, should an undergraduate science course be structured? At the most general level, the classroom is really the best opportunity for students to be interacting with the professor, who's the expert in the subject, and their fellow students.

2. Learning by Actively Practicing

What we know about learning from cognitive psychology is that people learn by practicing, with feedback to tell them what they're doing right and wrong and how to get better. In this case, that means they need to practice thinking like a scientist in the field. They should do background reading that gives basic information before class and then in class they're working through carefully designed problems that give them practice at a particular sort of scientific thinking, whether it's how physicists think about forces in motion, or how biologists think about cells and how they repair themselves, and so on. This way, they get much more targeted feedback from the instructor, who can realize they're confused about some basic point and can guide them much more directly. In this way, students spend all of their time in class being very actively involved, using their brains strenuously. They would also have homework problems that build on what they've done in class, so they can practice more extensively. The basic issue is practicing scientific thinking and getting guiding feedback on their thinking.

Is there any place for lecturing in undergraduate science and math courses? Is there a place for telling students something? Yes, absolutely. For example, after students have worked through a series of problems, they might all be wondering how you make the next step and then the instructor, in response to questions, would explain things to them.

Should lecturing be abolished in K to 12 science classes also? The same principles of how people learn apply to all education levels. Most K-12 teachers would not expect students to listen quietly and passively while they were being talked at for an hour. But one of the particular challenges of introducing these kinds of effective teaching methods at the K to 12 level is that they really require more subject expertise from the instructor than a lecture. A lecture is basically a talking textbook. But in these methods I'm talking about, you really have to think about how scientists think about and solve problems in a particular area and then design appropriate problems that have students practicing and learning that thinking. Then you have to be able to give the students feedback on how they're thinking. That is very demanding on your expertise in the subject. At the K-12 level, although there certainly are exceptions, teachers by and large do not have high enough content mastery to do this very well. In large part, that's because they've been through college courses where the science is taught badly, so they didn't learn it very well. So, they're graduating with a deficient understanding of the subject and a deficient view about how to teach it. So, before you can expect K-12 science teaching to get much better, you have to fix the science teaching in colleges and universities.

Some more open questions: What is the optimum way of designing these practice problems? What features of a problem are the most effective in terms of having students start more quickly and effectively taking an expert-like problem solving approach? Are online interactive simulations good enough? What are the most effective ways to use new educational media to accomplish learning in new ways?

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Teaching Science by Active Learning

by *Mitchell Waldrop*

1. Active Learning

Outbreak alert: six students at the Chicago State Polytechnic University in Illinois have been hospitalized with severe vomiting, diarrhea and stomach pain, as well as wheezing and difficulty in breathing. Some are in critical condition. And the university's health center is fielding dozens of calls from students with similar symptoms.

This was the scenario that 17 third- and fourth-year undergraduates dealt with as part of an innovative virology course led by biologist Tammy Tobin at Susquehanna University in Selinsgrove, Pennsylvania. The students took on the role of federal public-health officials and were tasked with identifying the pathogen, tracking how it spreads and figuring out how to contain and treat it - all by the end of the semester.

Although the Chicago school and the cases were fictitious, says Tobin, «we tried to make it as real as possible». If students decided to run a blood test or genetic assay, Tobin would give them results consistent with enterovirus D68, a real respiratory virus. (To keep the students from just getting the answer from the Internet, she portrayed the virus as an emergent strain with previously unreported symptoms.) If they decided to send a team to Chicago, Tobin would make them look at real flight schedules and confirm that there were enough seats.

In the end, the students pinpointed the virus, but they also made mistakes: six people died, for example, in part because the students did not pay enough attention to treatment. However, says Tobin, «that doesn't affect their grade, so long as they present what they did, how it worked or didn't work and how they'd do it differently».

What matters is that the students got totally wrapped up in the problem, remembered what they learned and got a handle on a range of disciplines. «We looked at the intersection of politics, sociology, biology, even some economics», she says.

Tobin's approach is just one of a diverse range of methods that have been sweeping through the world's undergraduate science classes. Some are complex, immersive exercises similar to Tobin's. But there are also team-based exercises on smaller problems, as well as simple, carefully tailored questions that students in a crowded lecture hall might respond to through hand-held 'clicker' devices. What the methods share is an outcome confirmed in hundreds of empirical studies: students gain a much deeper understanding of science when they actively grapple with questions than when they passively listen to answers.

«We find up to 20% better grades over usual methods», says Tom Duff, a computer scientist who developed a team-based learning approach at the University of the West of Scotland in Paisley, UK. Other active-learning proponents have found similar gains. Last year, a group led by biologist Scott Freeman at the University of Washington in Seattle published an analysis of 225 studies of active learning in science, technology, engineering and mathematics (STEM) and found that active learning cut course failure rates by around one-third.

«At this point, it is unethical to teach any other way», declares Clarissa Dirks, a microbiologist at the Evergreen State College in Olympia, Washington, and co-chair of the US National Academies Scientific Teaching Alliance, an initiative to reform undergraduate STEM education.

Active learning is winning support from university administrators, who are facing demands for accountability: students and parents want to know why they should pay soaring tuition rates when so many lectures are now freely available online. It has also earned the attention of foundations, funding agencies and scientific societies, which see it as a way to patch the leaky pipeline for science students. In the United States, which keeps the most detailed statistics on this phenomenon. About 60% of students who enroll in a STEM field switch to a non-STEM field or drop out. That figure is roughly 80% for those from minority groups and for women.

2. Tough Sell

Not everyone embraces the idea. Active learning can be a tough sell to faculty members who thrived on standard lectures during their own student years and who wonder whether the benefits of active learning - which requires substantially more preparation than do standard lectures - could possibility justify the time that the approach would take away from their research.

Understanding and addressing the resistance has become one of the reformers' prime concerns. Robert Lue, the other co-chair of the teaching alliance and director of the Derek Bok Center for Teaching and Learning at Harvard University in Cambridge, Massachusetts, says that he is «hell bent on erasing this sense that research is where you apply your intellect and teaching is a rote skill». Scientists need to approach teaching with the same rigor and appreciation for evidence that they exercise in the laboratory, he says. «It's at the frontier of research. And the more people we get involved, the faster that research will go».

On the surface, active-learning classes can seem to differ little from more conventional approaches. Undergraduate students have always had discussion sessions to ask about the course material and laboratory classes in which they would carry out experiments. But if you look more closely, says Tobin, these are often just 'cookbook' exercises. The typical approach is «read that and be prepared to talk about these questions», or «follow that procedure and you'll get this result». In an active-learning class such as hers, she says, the students take charge of their own education. «They are framing the questions themselves».

The same is true for active learning in first-year courses, in which the teachers often do supply the questions - but frame them in a way that asks for more than a rote recitation of facts. It is the difference between «name the sensory nerves of the leg» and what neuroscientist Sarah Leupen asks of her introductory physiology class at the University of Maryland, Baltimore County (UMBC):

You're innocently walking down the street when aliens zap away the sensory neurons in your legs. What happens?

a) Your walking movements show no significant change.
b) You can no longer walk.
c) You can walk, but the pace changes.
d) You can walk, but clumsily.

«We usually get lots of vigorous debate on this one», says Leupen, who spends most of her class time firing such questions at her students. «It's lovely to experience».

What makes those questions special is that the students cannot answer them simply by reading the course material - although they are expected to have done that before attending class. Instead, they have to apply what they have learned, which they do by clustering around tables in small teams and arguing over the options. That struggle is the real pay-off, says Leupen, who eventually explains the right answer (in this case, d). And if a team gets it wrong, she says, «that's usually a good thing - because then they really remember it».

3. Wieman's Conversion

Evidence has been accumulating for decades that students who actively engage with course material will end up retaining it for much longer than they would have otherwise and they will be better able to apply their knowledge broadly. But the evidence began to draw widespread attention only around the turn of the century - in great part thanks to Carl Wieman, who suddenly became one of the movement's most visible champions when he was awarded the 2001 Nobel Prize in Physics for his co-discovery of Bose-Einstein condensates. «I started way before the Nobel prize», says Wieman, who is now at Stanford University in California. «It's just that people didn't pay attention to me until then».

Wieman's conversion began in the late 1980s, when he noticed something about the graduate students coming into his atomic-physics lab - then at the University of Colorado Boulder. «They had done really well as undergraduates, but couldn't do research», he says. Over the years, they learned how to be good scientists, «but that had little to do with how well they had done in their courses».